AN ITERATIVE APPROACH TO DEVELOP A COGNITIVE MODEL OF THE DRIVER FOR HUMAN CENTRED DESIGN OF ITS

Benoît Mathern[1, 2], Thierry Bellet[1], Alain Mille[2]
[1] INRETS, LESCOT, 69675, France
2 Université de Lyon, CNRS
[2] Université Lyon 1, LIRIS, UMR5205, F-69621, France
benoit.mathern@inrets.fr

ABSTRACT: Applying a Human Centred Design (HCD) approach to Intelligent Transportation Systems (ITS) is a challenging issue. Indeed, it is fundamental to confront the end-user to the designed system as often and as soon as possible. However, this process is both costly and time-consuming. We present several ways in which driver models, especially cognitive models, could support the HCD of driving assistance systems. As developing and implementing a cognitive model is a very challenging issue, we propose an iterative method to develop such a model. This method relies on the cognitive framework COSMODRIVE and on specific Knowledge Engineering tools.

1 CONTEXT AND OBJECTIVES: HUMAN CENTRED DESIGN FOR ITS

The Human Centred Design (HCD) approach aims to provide an improved integration of the end-user's effective needs in the system design process, starting from the very beginning of the design process. HCD is defined in ISO13407 0 as an iterative loop (see 0). The four main steps comprising the loop are: i) specify the context of use, ii) specify user and organizational requirements, iii) produce design solutions, iv) evaluate designs against user requirements and needs.

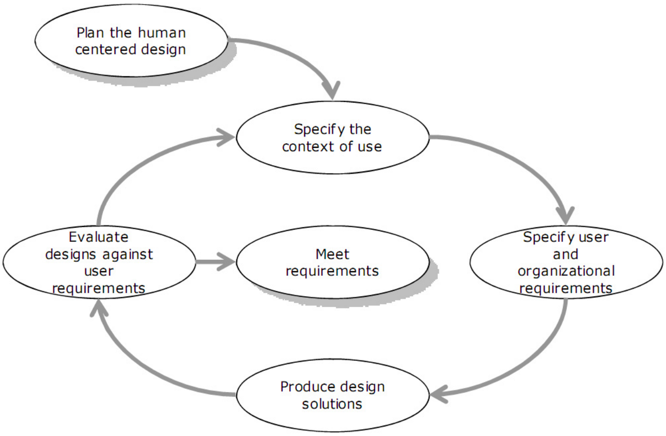
Plan the human centered design
Specify the context of use
Specify user and organizational requirements
Produce design solutions
Evaluate designs against user requirements
Meet requirements

Fig. 1: Basic HCD loop from ISO13407 0

Applied to Intelligent Transportation Systems (ITS) and driving assistance system design, the context of use refers to driving scenarios, the user requirements refers to the driver's needs of assistance about functions, human-machine interaction and device acceptance.

Every time the human operator appears in this loop, there is a need of feedback from the end-user: either by ergonomics expertise, or by experimenting with end-users. However, such feedback from users is costly, time-consuming and restrictive. On the contrary, using a model of the driver in a virtual environment would make it possible to run numerous simulations, with various scenarios, virtually costless and within a short amount of time. Thus, driver modelling is a real challenge for increasing the number of cycles of the HCD process, and then improving the resulting system design.

In this paper, we will present, in section 2, an overall approach of driver modelling for HCD. Then, in section 3, we propose a method and a set of tools to iteratively build such a model. Finally, in section 4, we will discuss our approach and conclude.

2 METHODOLOGICAL APPROACH: MODELS OF THE DRIVER FOR HCD

In this section, we will first have an overview of several types of driver models, and see how they can support the HCD. Then, we will show a methodology to develop a cognitive model of the driver.

2.1 Models of the driver

The expression "driver modelling" is used in several fields. In this article, we only focus on models with regard to the car-driving activity. We do not consider for instance bio-mechanical models or aircraft piloting activity. From now, we will use indifferently the terms "model of the driver" or "driver model" to refer to a model which focuses on the car driving activity, in its behavioural or cognitive aspects.

Still, what we call "driver modelling" covers different parts of the driving activity and different kinds of models. First, we can make a classical distinction, on what is modelled: between behavioural models and cognitive models 0. Behavioural models focus on the driving performance, while cognitive models focus on the cognitive processes underlying the performance. We also make another distinction, on the scientific use of the model: either for analysing the activity 0, or for simulating it 0. Models for analysis produce a diagnosis on a driving performance, while models for simulation produce the driving performance itself. Moreover, all those types of model have both a theoretical part (e.g. in cognitive psychology for cognitive models) and an implementation part, involving engineering work. 0 illustrates those different types of model and their potential use.

Different types of computational models of the driver, and their potential use, regarding to their analysis/simulation role and their behavioural/cognitive nature.

Types of Driver Models	Models for Analysis	Models for Simulation
Cognitive Models	Cognitive status assessment models (e.g. level of distraction of the driver, erroneous situation awareness).	Cognitive simulation models (simulation of mental functions like information processing, mental model, decision-making, action planning, etc.).
Behavioural Models	Performance assessment models (e.g. behaviour adequacy judgment, detection of inappropriate manoeuvre).	Performance simulation models (simulation of the driving performance itself).

Of course, a model can have several facets. Typically, a model can have both cognitive and behavioural parts. For instance, when connecting a cognitive model to a real driving situation, the model has to be linked to a behavioural model or to some behavioural data. A cognitive model for analysis will infer cognitive states of the driver from behavioural data collected in the vehicle. A cognitive model for simulation has to be linked to the world in order to update its mental representation, or to actually produce the actions planed at the cognitive level. Such a cognitive model for simulation would be very attractive regarding its potential ability to explain human errors: from their cognitive origins to their behavioral consequences.

2.2 How to use a model in the HCD approach?

Models can be used in the HCD loop of 0 in two main ways (see examples in 0):

1) As a source of knowledge, the model could help to specify or evaluate the design of an assistance system. As explained in section 0, a model could be used in the phases of the HCD in which the human operator feedback is needed. The model would support the HCD by saving time, saving cost and potentially improving the final system with more iterations of the HCD loop.

2) As part of the assistance system, the model could produce a real-time diagnosis on the activity, and adapt the assistance accordingly. Or as a co-driving system, the model could take partial or total control of the vehicle.

Potential contributions of cognitive driver models for the HCD of a Driving Assistance System (DAS).

Contributions of a driver model for the HCD of a DAS.	HCD process		DAS design	
	Specifying user's needs and context of use.	Evaluating an assistance system.	Real-time diagnosis of driver's activity.	Partial control of the vehicle.
Type of cognitive model that could be used.	Cognitive model for simulation.	Cognitive model for analysis.	Cognitive model for analysis.	Cognitive model for simulation.
An example of contribution of that model.	Design use-cases for the DAS; test a wide range of driving situations in order to specify which precise situation the DAS has to cover.	Test a DAS on a wide range of driving situations to evaluate the functioning of the DAS with a "driver".	Diagnose the activity in which the driver is involved and his or her situation awareness, in order to provide the driver with appropriate warning or assistance.	Diagnose the activity as a co-driver would do, and provide the driver with appropriate co-driving assistance, by potentially taking part of the control of the vehicle.

Of course, if we use a model to specify driver's needs for an assistance system, we would expect the model to make the same errors as the real drivers. It would be even better to have explanation of the origin of these errors, which could be for example, attentional or perceptual deficit, leading to inappropriate situation awareness (Endsley 0). Cognitive models are meant to explain or diagnose such human activity and errors. That is why, among the different types of driver models, cognitive models seem the most interesting to us. In the following, we will see a general approach to build a cognitive model.

2.3 A method to develop a cognitive model of the driver

Developing a cognitive model is quite difficult, as cognition is not directly observable. However, experimenting and observing are the main ways of acquiring knowledge on cognition and driving activity (see 0). Therefore, studying cognition, or modelling cognition, generally implies to plan experiments. One makes research hypothesis that the experiment will test. Step by step, it leads to strengthen the knowledge on cognition and improve the theoretical model.

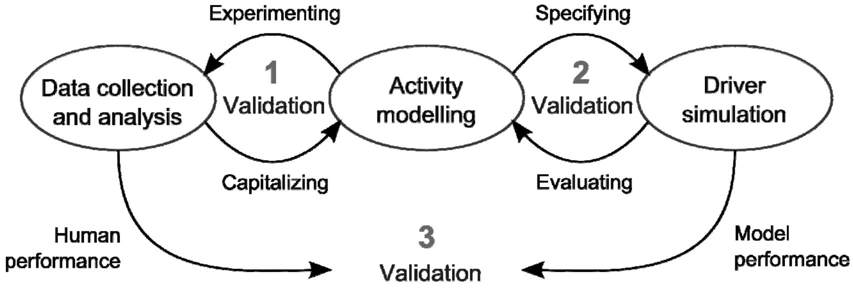

Fig. 2: Validation loops for cognitive modelling

Another way to test and develop a model would be to make it drive. For this purpose, we need a (computational) model for simulation. We could plug the model into a virtual platform, like a driving simulator, and make it drive in this virtual environment. Then, we could compare its performance to what we expected, or to the performance of real drivers.

In this paper, we focus on developing cognitive models of the driver for simulation purpose. This let us benefit from the three possible validation approaches described in 0. Building a cognitive model for simulation of the driver is a very challenging issue. As far as we know, there is no fully functioning model of this kind. Thus, we think it is very important to define an approach and tools that can give us a chance to succeed in this ambitious project.

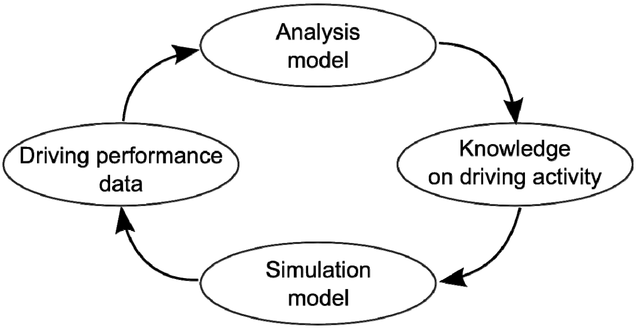

Fig. 3: An iterative approach to develop a cognitive model

We propose a general and iterative method to build such a cognitive model (see Fig.3). First, we have to collect data about human driving performance. Then, from these data, we build and use an analysis model to produce knowledge about the driving activity. Then, we introduce this knowledge into the simulation model. The simulation model is immersed in a virtual environment with which it interacts, to produce a driving performance. Then this performance can be compared to human performance, for validation purpose. We can re-iterate this modelling loop, starting again from human performance or from the model's performance, in order to complete and refine the model.

3 A FRAMEWORK TO SUPPORT ITERATIVE COGNITIVE DRIVER-MODELLING

In this section, we present how we plan to apply the iterative approach introduced in Fig. 3. First, we highlight two issues raised when iteratively extending a cognitive model. Then, we introduce methods to tackle those issues. An illustrative example shows how it works, and finally, we introduce existing and future tools that support this modelling approach.

3.1 Two issues for extending a cognitive model

The first issue is linked to the specificity of cognitive modelling: knowledge about cognition and car-driving activity is quite broad; however cognition is not directly observable. We cannot collect data capturing the whole complexity of cognition, especially in the case of the car-driving activity. Hence, data can be considered as a source of knowledge only if experts in cognition and in the driving activity can interpret their meaning. In other words, knowledge in cognition cannot be found blindly in the data; our method has to combine knowledge coming both from data and experts. The second issue is linked to the iterative process: how to make sure the previous model, of previous iteration loop, can be reused? How to make sure it can be combined to the new knowledge of the new loop, updating the model? Our method has to support iterative update of the model, or of part of it.

3.2 A framework to support iterative extension of a cognitive model

For supporting cognitive modelling, we have chosen on the one hand, to rely on a theoretical model of cognition; on the other hand, to rely on a computer science approach for extending the cognitive model. We will see how this choice supports both issues of iteratively extending the model and of combining knowledge coming from data and expertise.

On the one hand, we use a particular cognitive framework, developed at INRETS-LESCOT, called COSMODRIVE (Cognitive Simulation Model of the DRIVEr) 0. COSMODRIVE is a cognitive model of the driver, in terms of psychological modelling, that is to say a conceptual framework. It has been partially implemented as a software model. COSMODRIVE model does not only define some cognitive functions and a way they are orchestrated, but it also defines a knowledge structure, called driving schemas. Driving schemas are a way to represent operative knowledge about the driving activity. By “operative knowledge”, we mean a knowledge that can be directly used to produce an activity.

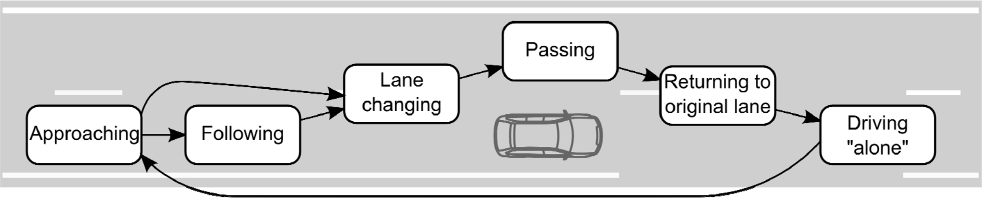

Fig 4 The successful-overtaking tactical schema on highway: activity phases (boxes) and links between phases (arrows), related to the decision process.

A driving schema focuses on a particular situation (for example, a left turn, an overtaking…) and on a particular level of the activity (strategic, tactical or operational, as defined by Michon 0). In COSMODRIVE, a tactical schema is composed of a sequence of “activity phases”. An activity phase is associated to a driving evolution zone, where the car moves, and to one or several perceptive exploration zones, where the driver looks for information. The activity phase is therefore associated with tactical goals and with the underlying operative processes, further divided into sub-schemas (operational schemas). While driving, the driver takes decisions that lead to shift from a schema to another or from an activity phase to another. As an example, 0 illustrates the activity phases (boxes) for the tactical schema of a successful overtaking on highway. When approaching or following a car, the driver can make the decision to overtake, thereby transitioning (arrows) into another activity phase, i.e. from "Approaching" (or "Following") to "Lane Changing". The goal of the "Lane Changing" phase is to change lane. The sub-schema of this phase contains several operational steps as turning the indicator on, turning the steering wheel, accelerating… Driving schemas are interesting for iterative modelling, as they can be cut into activity phases and then refined.

On the other hand, in order to iteratively build and extend the driving schemas models, we follow a knowledge engineering approach, called knowledge discovery 0. The goal of knowledge discovery is actually to help the expert to discover interesting patterns and knowledge both from data and from his or her own expertise. It relies on interactive software that takes benefit of both the calculation power of computers for finding patterns on a large set of data and the human capability to understand these data, interpret their meaning and formalise knowledge. This approach is based on iterative and interactive loops. If the patterns found by computation make sense to the expert, we get a new formal knowledge that can be reused. If the patterns discovered by computation don't make sense, the expert can check the input data or add, explicitly, some of his or her knowledge into the system in order to get more relevant results.

In summary so far, experts in cognition will use tools supporting the knowledge discovery approach. These tools are interactive and support the experts in producing reusable knowledge about cognition, in our case driving schemas, from experimental (mainly behavioural) data.

3.3 An illustrative example of the modelling loop

Our approach takes place as follows. First, we collect experimental data about driving activity. These data comes mainly from sensors on an instrumented car or a driving simulator. Experts use a knowledge discovery tool, called ABSTRACT1, to discover meaningful patterns into the data. They interact with this tool in order to interpret patterns found by some algorithms and to add explicit knowledge that helps to discover new patterns. Practically, the goal is to reformulate the raw data, into meaningful data about activity. It is like "translating" data from one language to another. Several reformulations of the data are needed to describe the activity in the "vocabulary" of car-driving activity and cognition. When such a level of description of the activity is reached, half of the work is done. We are able to "read" the activity at the cognitive level.

[1] ABSTRACT: Analysis of Behavior and Situation for menTal Representation Assessment and Cognitive acTivity modelling

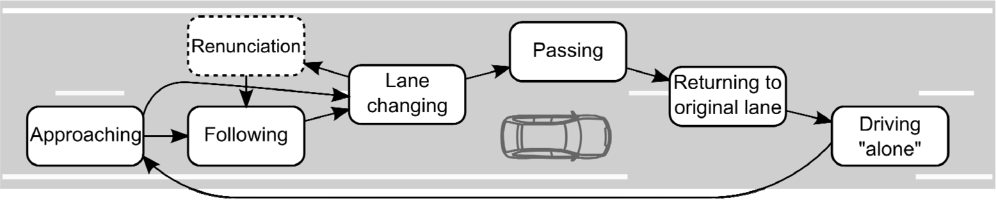

Fig 5 The overtaking tactical schema on highway: activity phases (boxes) and links between phases (arrows), related to the decision process.

The next step consists in discovering the structure of the activity. Another knowledge discovery tool, called AUTOMATA2 will be used for this purpose. The structure of the activity is an essential point of driving schemas. It describes for example which phase of a driving schema always follows another one, or it expresses the choice (decision process) between two next possible phases. It is like knowing the "grammar" of the activity.

For example, with ABSTRACT approach, we can study a particular driver activity. Based on his situation awareness, the driver takes the decision to overtake. Then, involved in the "Lane Changing" activity phase, he begins to turn the indicator on, and starts turning his steering wheel. After a last check at the left mirror he discovers a car coming on the left lane. He realises his error and has to give up his overtaking ("Renunciation" phase). With AUTOMATA approach, we combine this case to the previous knowledge on the tactical overtaking schema to produce a more general driving schema of overtaking (See 0).

If we follow the language metaphor, we now have a "vocabulary" and a "grammar". We can now "write" full sentences. We can now use driving schemas to simulate a cognitive activity. Thus, by plugging those driving schemas into a proper driving simulation environment, the model could drive and produce a driving performance.

Then a next iteration of the modelling loop (section 0) can begin. New human driving performance, or the model's driving performance itself, will be analysed, and used to validate, complete or refine the model.

3.4 Tools supporting this iterative modelling approach

We will introduce mainly two tools to build a cognitive model of the driver: ABSTRACT and AUTOMATA. Both tools rely on a knowledge discovery approach, in order to interactively produce knowledge about driving schemas.

ABSTRACT 0, 0 is based on the activity trace formalism 0, developed at LIRIS laboratory. An activity trace is sequence of observed elements of an activity (e.g. events, objects, states). This formalism has been designed to capture the human activity in its interaction with the environment. ABSTRACT tool was

[2] AUTOMATA: AUTOmata Modelling of the Activity, based on Trace Analysis

designed to analyse driving activity data. ABSTRACT helps the expert to reformulate the trace coming from raw experimental data into a meaningful trace related to driving activity and cognition. ABSTRACT has been successfully used for driving activity analysis, in a case study on lane changes 0. 0 shows a labelled screenshot of ABSTRACT tool. The horizontal axis represents the time axis and the vertical axis roughly represents the level of abstraction of the observed elements. The round dots represent observed elements of raw data (e.g. from sensors). The triangles and squares represent a reformulation of those low level observed elements into higher level "inferred elements". They correspond to a new trace, describing the lane changing activity (here, at the operational level).

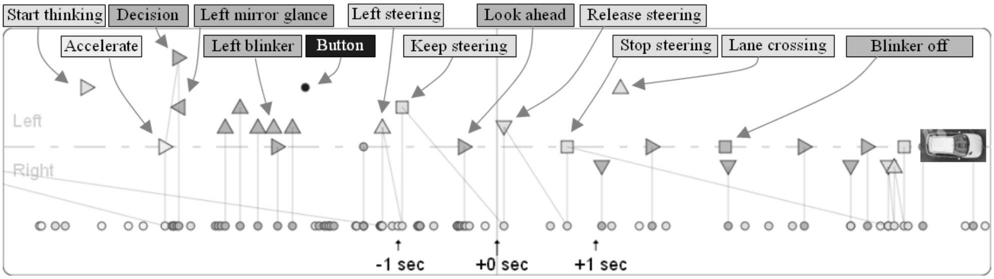

Fig 6 ABSTRACT screenshot presenting a typical lane change.[3]

AUTOMATA approach aims to fill the missing step between the activity trace that describes cognition, and a simulation model, that would produce an activity. In other words, AUTOMATA approach will help the expert to build driving schemas from the description of the activity found in the traces. The output of AUTOMATA tool is an automaton (Petri-nets). The automaton formalism is well suited for representing driving schema: it can produce an activity, therefore it can be integrated into a simulation model, and it has a graphical representation that experts (in cognition) can understand and interpret. Actually, 0 and 0 use a graphical representation of automata to express driving schemas. Making sense out of data is mandatory for our approach.

AUTOMATA tool is currently being developed. It will adapt some "automatic" process mining techniques 0 to make them interactive, so that the expert can build an automaton model of the activity he or she is analysing.

The last step would be to integrate those driving schemas into a driving simulation environment, in order to test the driver performance of the model. Work is in progress, to integrate COSMODRIVE framework into SiVIC[4] virtual platform for simulation. The resulting tool, called COSMO-SiVIC will be able to integrate driving schemas produced by the AUTOMATA approach, and then complete the simulation loop.

[3] See http://liris.cnrs.fr/abstract/ for more information.
[4] SiVIC is a platform developed by LIVIC laboratory (INRETS/LCPC).

4 CONCLUSION AND PERSPECTIVES

In this paper, we have introduced how driver models could be used in the HCD approach. From different types of models, we have chosen to focus on cognitive models, because they seem to us the most interesting, regarding to the HCD issue. However, they are very complex to build, which motivates us to propose a method to build them. This method is supported by the COSMODRIVE cognitive framework and by specific Knowledge Engineering tools. As this method is iterative, and cut the cognitive modelling problem into a smaller problem (driving schemas), we plan to get rapidly a partial cognitive model. However, time is needed to get a complete model. It is also important to note that driving schemas does not model all the cognition or cognitive processes (i.e. no mental representations). Thus, driving schemas, taken alone, are not sufficient to get a complete cognitive model of the driver. Driving schemas have to be integrated into a more complex model. Current research is in progress in the ISi-PADAS European project 0 for developing such a model.

5 ACKNOWLEDGMENTS

This work was supported by Région Rhône-Alpes and the "Transport, Territories and Society" Cluster.

6 REFERENCES

ISO 13407: 'Human centred design processes for interactive systems', 1999

Bellet, T., Bailly, B., Mayenobe, P., and Georgeon, O.: 'Cognitive modelling and computational simulation of drivers mental activities', in Cacciabue, P.C. (Ed.): 'Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems' (Springer, 2007), pp. 315–343.

Henning, M., Georgeon, O., Wynn, T., and Krems, J.: 'Modelling driver behaviour in order to infer the intention to change lanes', European Conference on Human Centred Design for Intelligent Transport Systems, 2008, pp. 113–120.

Bellet, T., Bailly-Asuni, B., Mayenobe, P., and Banet, A.: 'A theoretical and methodological framework for studying and modelling drivers' mental representations', Safety Science, Elsevier, 2009, 47, 9, pp. 1205–1221.

Endsley, M.R.: 'Toward a theory of situation awareness in dynamic systems', Human Factors, 1995, 37, (1), pp. 32–64.

Michon, J.A.: 'A critical view of driver behavior models: what do we know, what should we do?', Human Behavior and Traffic Safety, Plenum Publishing Corporation, 1985, pp. 485–520.

Fayyad, U., Piatetsky-Shapiro, G., and Smyth, P.: 'From data mining to knowledge discovery in databases', AI Magazine, 1996, 17, (3), pp. 37–54.

Georgeon, O., Henning, M., Bellet, T., and Mille, A.: 'Creating Cognitive Models from Activity Analysis: A Knowledge Engineering Approach to Car Driver Modeling', International Conference on Cognitive Modeling, Taylor & Francis, 2007, pp. 43–48.

Georgeon, O.: 'Analyzing traces of activity for modeling cognitive schemes of operators', AISB Quarterly, 2008, 127, pp. 1–2.

Settouti, L.S., Prié, Y., Champin, P., Marty, J., and Mille, A.: 'A Trace-Based Systems Framework : Models, Languages and Semantics', scientific report, 2009, available from: http://hal.archives-ouvertes.fr/docs/00/38/98/52/PDF/trace.pdf, accessed January 2010.

Van der Aalst, W.M.P., Van Dongen, B.F., Herbst, J., Maruster, L., Schimm, G., and Weijters, A.: 'Workflow mining: A survey of issues and approaches', Data & Knowledge Engineering, 2003, 47, (2), pp. 237–267.

http://www.isi-padas.eu/, accessed March 2010